FIELD TEST PROGRAM

FINAL REPORT

FT-45 SUPPLEMENT

TAMPER RESISTANT DATA LINK

DECEMBER 1970

UNITED STATES ARMS CONTROL
AND DISARMAMENT AGENCY

37

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The Field Operations Division of the Weapons Evaluation and Control Bureau assumes overall responsibility for the development of this document. Braddock, Dunn and McDonald, Inc., under contract ACDA/WEC-169, contributed to its contents.

This document reports on part of a program of research on inspection and verification and does not express a U.S. position.

Prepared by

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ABSTRACT

The FT-45 Supplement was a test of a semi-flexible data link. The tampering techniques developed in FT-45 were utilized in determining the tamper-resistance of this more flexible cable. Also demonstrated was a new time domain reflectometry (TDR) technique which provides an increased capability for detecting high impedance probes connected to the cable.

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SYNOPSIS

A. PURPOSE

The purpose of the FT-45 supplemental testing program was to extend the range of applicability of the time domain reflectometry as a means of protecting arms control inspection data during transmission. This program determined the tamper-resistance of a data link, more flexible and smaller in diameter than that tested in the previously reported FT-45 test, but utilizing the time domain reflectometry techniques developed in FT-45. These two cable characteristics, smaller diameter and greater flexibility, reduce installation problems making this cable more attractive for arms control data transmission applications.

B. BACKGROUND

The use of unattended sensors for arms control inspection has considerable appeal from the point of view of reducing the cost and intrusiveness of inspection. To be credible, equipments intended for unattended operation must have provisions for ensuring that the data during both collection and storage are valid and have not been falsified. The feasibility of using time domain reflectometry (TDR) as a technique for protecting data during transmission from the sensor to a secured recording station was demonstrated during FT-45. The cable utilized in the FT-45 experiment was semi-rigid and had a diameter of 1.75 inches. These two properties make installation difficult in some situations. In order, therefore, to increase the range of application of this means of data protection, the supplemental testing program described herein was undertaken.

C. DESCRIPTION OF DATA LINK

The cable selected for the FT-45 supplemental experiment was semi-flexible with a 5-inch radius of curvature and a ½-inch diameter. The FT-45 cable was semi-rigid with a 25-inch radius of curvature and a 1 3/4-inch diameter. The data link consisted of two coaxial cables, one within the other. The inner coax would be used to transmit inspection data. It is constructed of a teflon jacket and

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dielectric with an outer copper mesh shield and an inner copper conductor. This coax is threaded through the hollow inner conductor of a larger coaxial cable which consists of an aluminum outer conductor, foamed polyethylene dielectric and a hollow copper inner conductor.

The purpose of the outer coaxial cable is to inhibit access to the inner coaxial cable which carries the data. To get to the inner data conductor, one must first cut holes through the outer coaxial cable. The TDR, therefore, is used to detect changes in this cable's characteristic impedance resulting from such holes and from probes inserted through the holes. The TDR system accomplishes this by applying short, sharp electrical pulses to the cable and monitoring the cable for changes in the pattern of reflected energy.

To monitor or falsify inspection data one must attach probes to the data carrying conductor. The inner coaxial cable, therefore, is monitored with separate TDR signals to detect the presence of such probes.

D. SUMMARY OF RESULTS

The following specific technical results are based on the FT-45 supplemental contract work and apply to lengths of cable up to 175 feet. These results, in general terms, are similar to those observed during the previous FT-45 tests although there are differences in many of the details.

1. Outer Coaxial Cable (RG 231/U)

a. A 3/16-inch hole in the outer shield of the cable is definitely detectable and a 1/8-inch hole is marginally detectable by examination of the TDR signatures.

b. The combination of 7/64-inch holes in both the outer and inner shields is marginally detectable and with 1/8-inch holes is definitely detectable.

c. Holes of smaller size which are not detectable would be adequate for inserting probes into the inner cable.

d. All diodes and probes which might be used to monitor the transmitted data or to inject false data are easily detectable when inserted through holes in the cable.

e. The cable is very sensitive to dents with a dent of 1/27-inch vertical deflection definitely detectable.

f. The cable is very sensitive to bending with one 90° or 180° bend affecting the TDR signature. Repeated bending at the same location on the cable results in sufficient distortion of the cable and its signature to interfere with the detection of tampering at that location.

2. Inner Coaxial Cable (RG 178 B/U)

a. A change in the slope of the TDR signature which corresponded to a change in impedance across the cable was apparent under all test conditions. Tamper location information was also indicated in the affected signature.

b. Probes of 2K ohms impedance or less attached across the cable are definitely detectable while 10K ohm resistances are marginally detectable.

E. CONCLUSIONS

1. The more flexible data link tested is highly tamper-resistant and no way could be found to inject false data without affecting the characteristic TDR signature of the cable. This data link can be used to protect data over distances of at least 175 feet.

2. The feasibility of TDR monitoring of the inner coaxial cable which carries the inspection data was demonstrated. The combination of TDR monitoring of both the inner coaxial cable and the outer coaxial cable presents the would-be penetrator with problems appreciably more difficult and complex.

3. The more flexible data link tested during the FT-45 Supplement is more sensitive to and will detect smaller holes than the previous cable tested in FT-45. However, the cable is also very sensitive to bends and dents making cable handling and installation more difficult.

F. RECOMMENDATIONS

The FT-45 supplemental contract work achieved the goals outlined in the test proposal, however, certain areas need additional development.

1. The phenomenon of a changing slope in the TDR signature associated with a change in impedance across the RG 178 B/U data conductor was demonstrated as being significant enough to base a new detection technique upon it. However, only feasibility was demonstrated and additional engineering development would be needed to produce operational equipment.

2. Since the RG 231/U cable is susceptible to dents and bends, some means of physically protecting the cable would be required in many installations. It may be feasible to protect the cable with conduit. Alternatively, effort should be undertaken to find a flexible data link which is protected with an outer jacket.

3. The technique of TDR monitoring of the data conductor appears highly desirable but requires that the TDR and the data signals share a common conductor through the use of a filter system. If an operational requirement arises for a TDR system, additional developmental work in this area should be pursued.

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I. INTRODUCTION

A. PURPOSE

The purpose of the FT-45 supplemental testing program was to determine the tamper-resistance of a flexible data link utilizing the time domain reflectometry techniques developed in FT-45. The testing program was directed by the U.S. Arms Control and Disarmament Agency (ACDA) and conducted under contract ACDA/WEC-169 by Braddock, Dunn and McDonald, Inc. (BDM), the data link developer, with technical assistance from the National Bureau of Standards (NBS).

The initial FT-45 experiment tested a semi-rigid coaxial cable with an air-dielectric and hollow inner conductor. This work was accomplished under contract ACDA/WEC-155 with BDM and under ACDA/WEC/RA-51 with NBS. The results of this testing program are contained in the final report[1] dated June 1970.

B. BACKGROUND

The use of unattended sensors for arms control inspection has considerable appeal from the point of view of reducing the cost and intrusiveness of inspection. The feasibility of using time domain reflectometry as a technique for protecting data during transmission from the sensor to a secured recording station was demonstrated during FT-45. The need for a flexible data link was also demonstrated during FT-45 when it became apparent that the semi-rigid cable being tested was unacceptable for application to many situations due to the difficulties encountered in installing the cable.

Based on the FT-45 observations, a supplemental testing program utilizing the same equipments and the more flexible data link was initiated. A complete

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[1]FT-45 Final Report (ACDA/WEC 70-20) June 1970.

description of the equipments used in the supplemental test can be found in the FT-45 Final Report (ACDA/WEC 70-20, June 1970). The report also details the tamper characteristics an inspector will search for when evaluating a TDR trace of the cable.

C. DATA LINK DESCRIPTION

The data link is composed of two coaxial cables. A small cable, RG-178 B/U, which is actually the data carrying conductor is threaded through the hollow inner conductor of a larger coaxial cable, RG-231/U.

The outer protective cable (RG-231/U) is composed of an aluminum outer conductor, foamed polyethylene dielectric and a hollow copper inner conductor.

The data carrying coax (RG-178 B/U) is constructed of a teflon jacket and dielectric with an outer copper mesh shield and an inner 30 AWG (7x38) copper conductor.

A schematic diagram of the coaxial cables is shown in figure 1 and their characteristics are given in figure 2.

D. SYSTEM CONCEPT

The system concept developed for the two coaxial cables, as illustrated in figure 1, is to separately monitor both cables using the time domain reflectometer. Based on this concept, the tamper resistance of each cable is determined independently.

The purpose of the outer RG-231/U cable is to inhibit access to the RG-178 B/U data carrying inner conductor. To get to the inner data conductors, one must first cut holes in the RG-231/U, therefore, the TDR is used to monitor any changes in the cable's characteristic impedance resulting from such holes or from probes inserted through the holes. The RG-231/U is monitored with the intent of detecting as small a hole as possible

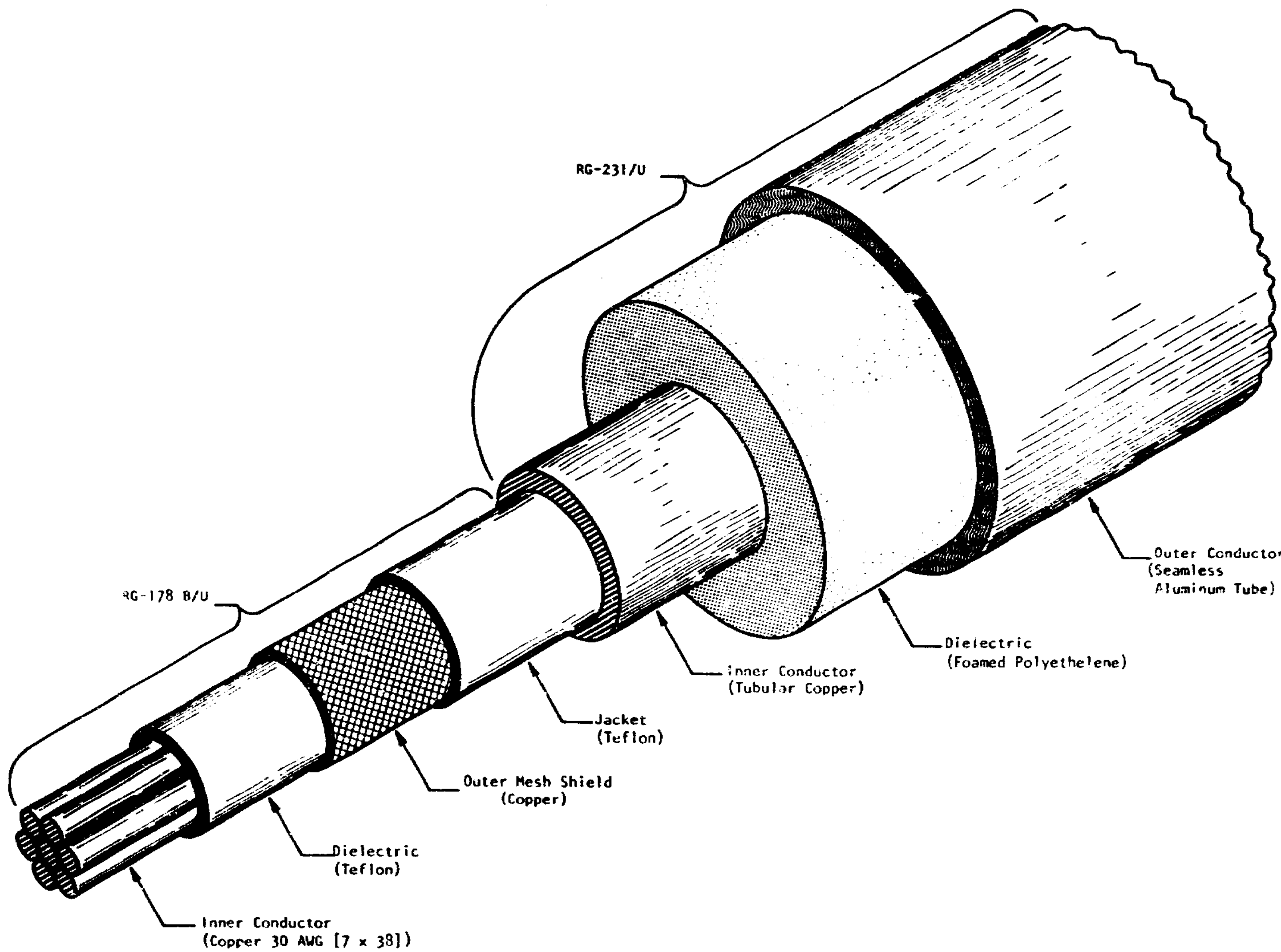


FIGURE 1. Schematic Diagram of Coaxial Cables

RG-231/U 50 OHM CABLE

1. Aluminum outer conductor OD = 0.500 in.
   ID = 0.450 in.
2. Copper inner conductor OD = 0.162 in.
   ID = 0.112 in.
3. No outer jacket
4. Dielectric = foamed polyethylene
5. Minimum bend radius = 5 in.
6. Cut off frequency = 10.0 GHz
7. Attenuation @ 3 GHz = 6.4 db/100 ft.
8. Maximum recommended operational voltage = 2.5 kv
9. Maximum pulling force = 200 lbs.
10. Weight per 100 ft. = 11.8 lbs.
11. Direct current resistance (R_{dc}) of RG-231/U = 0.15 ohm for 212 ft., 11 in. (measured with one end shorted)

RG-178 B/U 50 OHM CABLE

1. Nominal OD = 0.072 in.
2. Inner conductor 30 AWG (7x38) silver coated copper weld
3. Outer shield silver coated copper
4. Teflon insulation and jacket
5. Nominal velocity of propagation = 69.5%
6. Nominal capacitance = 29 micro microfarads per ft.
7. Attenuation at 400 megahertz = 29 db per 100 ft.
8. For 217 ft. of RG-178 B/U R_{dc} = 46 ohms (measured with one end shorted)

FIGURE 2. Cable Characteristics

in the cable, thereby forcing an intruder to work in a very limited space.

The sensor data is transmitted over the smaller RG-178 B/U coax cable. Since an intruder must insert a probe across the data conductor in order to monitor data or inject false data, the TDR is operated in a mode designed to detect as large an impedance as possible which is connected across the conductor.

Therefore, in testing the outer RG-231/U cable, reflections in the TDR pattern which are characteristic of holes and of probes inserted through the holes are searched for. In testing the inner RG-178 B/U cable, a change or discontinuity in the slope of the TDR trace is searched for because this is the characteristic generated by an impedance connected across the conductor.

Two possible system concepts which utilize the technique of protecting both data cables are described below. The first technique could be used when inspection data need not be transmitted continuously. This technique involves the continuous monitoring of the RG-231/U outer cable. The RG-178 B/U inner cable would also be monitored continuously except during two 30-second intervals each hour. During these two intervals, which would be randomly timed, the inspection data would be transmitted on the inner cable. The TDR would not monitor the inner cable while the data is being transmitted. As soon as the 30-second data burst was finished, the TDR would be switched back to monitor the inner RG-178 B/U line. Thus, the inner cable would be monitored for 59/60 of the time and the remaining minute would be divided into two 30-second random off periods. This would allow only a very short time for an intruder to attach a high impedance device to the inner cable and he would still have to do it without being detected on the continuously monitored outer cable. Other division of time between monitoring of the inner cable and data transmission could be used depending upon the required data rate.

A second technique would be to TDR both cables continuously. The outer cable would monitor for hole

penetrations and presents no unusual system difficulties. To monitor the data carrying inner cable continuously would require that the TDR and the data frequencies be separated sufficiently (i.e. data carrier not to exceed 4KHz) so as not to interfere with each other. In this mode of operation, the data transmitting and TDR monitoring units would operate in parallel. The input to the TDR would have a high pass filter to keep out the data carried at the lower frequencies.

This test reported herein, however, was not designed to determine the operational feasibility of a system, but only to determine the tamper-resistance of the flexible cable. System feasibility testing and prototype fabrication are recommended as possible future field test activities.

II. PRELIMINARY TESTING

A. GENERAL

Prior to actual testing of the cables at NBS, preliminary experiments were conducted by BDM. The purpose of these tests was to verify the cables' characteristics (figure 2) and to insure their general adequacy and suitability to a TDR monitor system. Penetration techniques used in the preliminary testing were based on techniques developed during FT-45.

B. EQUIPMENT ARRANGEMENT AND RESULTS

The test equipment used by BDM in the preliminary test included a Tektronix Model 549 oscilloscope and a Tektronix Model 1 S 2 TDR sampling unit.

1. RG-231/U. A schematic diagram of the equipment setup for testing the RG-231/U outer cable is shown in figure 3. The cable is operated with the ends shorted and the TDR pulse inserted at 50 cm from one end. This method of TDR operation was developed during FT-45. A complete description of this method can be found in the FT-45 final report. Total length of the cable used in this test was approximately 212 feet.

The preliminary test results indicate that a human inspector can marginally detect a 1/4-inch hole outer, 1/8-inch hole inner tamper condition at cable lengths up to 210 feet. The tamper was made at the end of the cable since this is the most difficult area of the cable for the inspector to detect tampering. The judgment on the detectability of holes is based on comparisons of X-Y plots of the different tampers. Figure 4 illustrates a 1/4-inch outer, 1/8-inch inner hole tamper, which is just barely discernable and a 5/16-inch outer, 1/8-inch inner hole tamper which produced the signature changes marked by the arrows. Close observation reveals that spikes, which are characteristic of a hole tamper, are apparent in case (b), while in

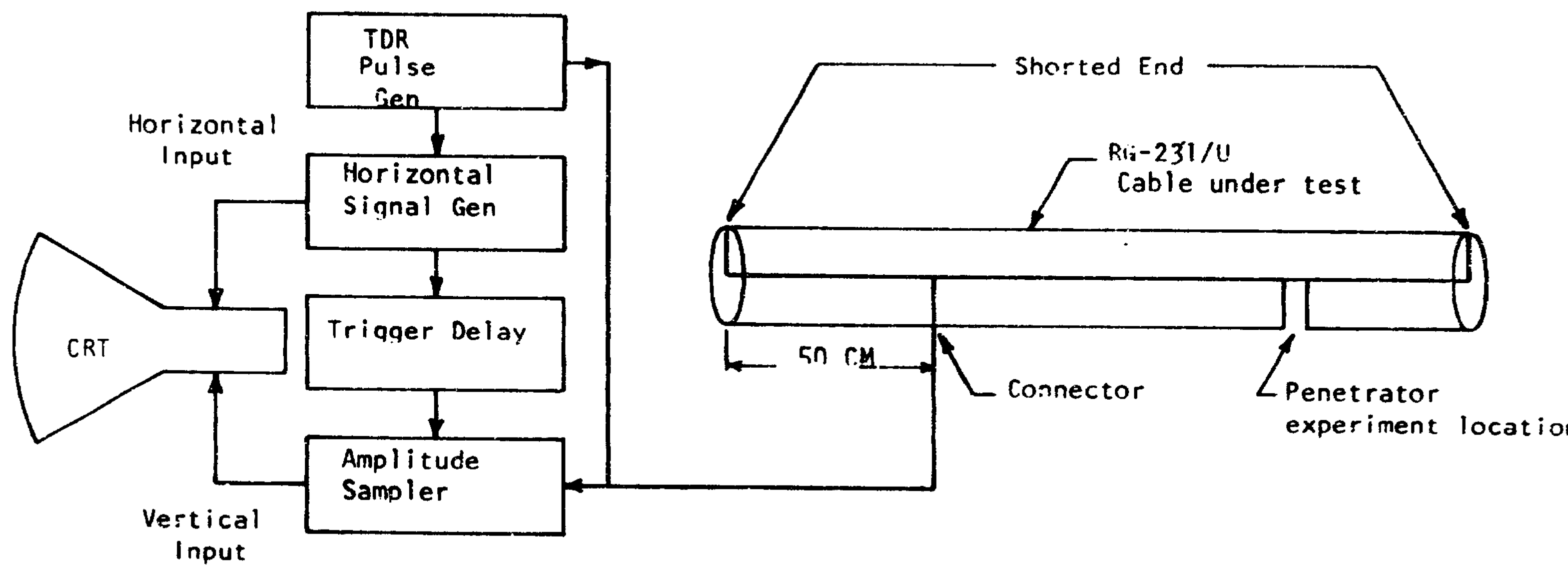
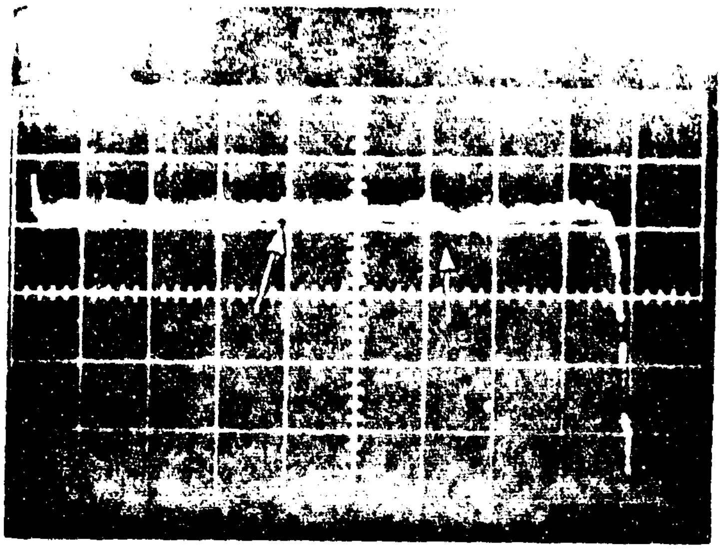
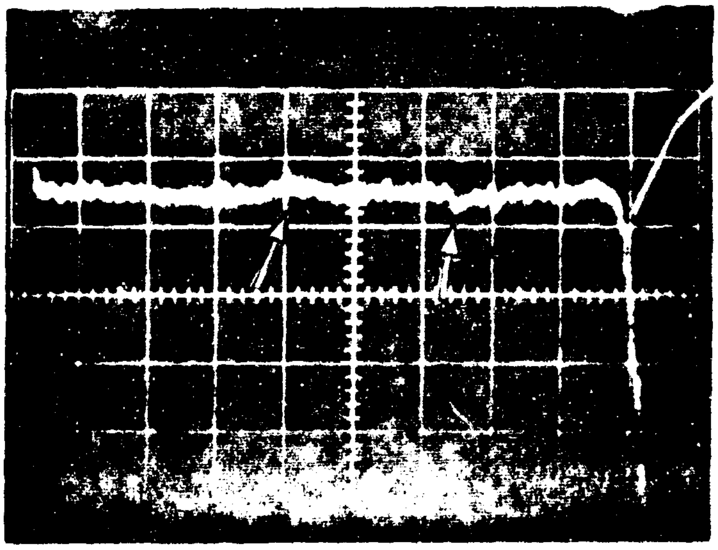


FIGURE 3. Schematic Diagram of the RG-231/U Test Setup with Oscilloscope Indicator



(a) 1/4 in. hole in the outer conductor
1/8 in. hole in the inner conductor



(b) 5/16 in. hole in the outer conductor
1/8 in. hole in the inner conductor

FIGURE 4. Various Size Holes Cut in the RG-231/U

case (a) they are not obvious. The 50-cm correlation, discussed in detail in the FT-45 final report, can be used by the inspector in evaluating the trace.

2. RG-178 B/U. A schematic diagram of the equipment setup for testing the RG-178 B/U inner cable is shown in figure 5. The TDR pulse is fed into the end of the coaxial cable with the test impedance attached to the other end. Again, as in the outer cable test, the further the tamper is from the TDR connection to the cable the more difficult it is to detect the tamper. In this preliminary test, the tamper was approximately 217 feet from the monitor.

Impedances ranging from 51 ohms to 10K ohms were tested on the RG-178 B/U cable. The conditions of the cable terminated in a short (zero impedance) and an open (infinite impedance) were also tested. Figures 6 and 7 illustrate what effect varying the impedance across the conductor has on the TDR plot of the cable. Figure 6(a) has been overlayed to 6(c) in order to demonstrate the effect of slope change that an inspector is searching for. Under actual inspection conditions, small changes in the slope could be difficult to detect, therefore, a light table would be used by the inspector in evaluating the X-Y traces.

Preliminary test results indicate that shorts and low impedance connections are readily detectable. In comparing conditions (a) and (b) of figure 6, however, there appears to be only minimum changes. This indicates that the marginally detectable impedance is between 2K ohms and 10K ohms.

It should also be noted that the tamper location is indicated by a discontinuity in the X-Y trace, as marked by an arrow in figure 6(b), and that the location on the trace is proportional to where the tamper occurs, therefore, tamper location information is contained in the X-Y trace.

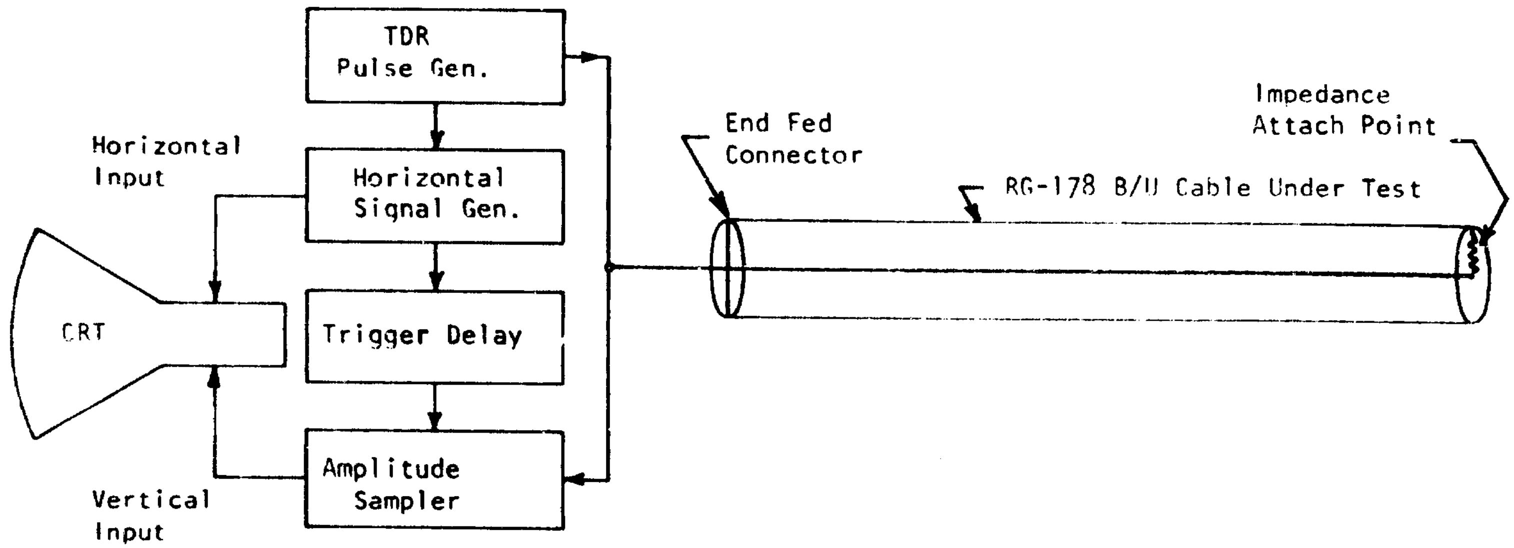
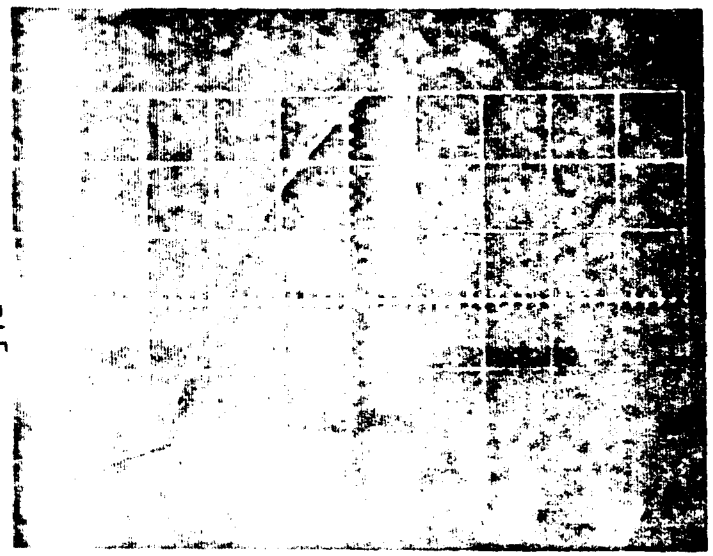
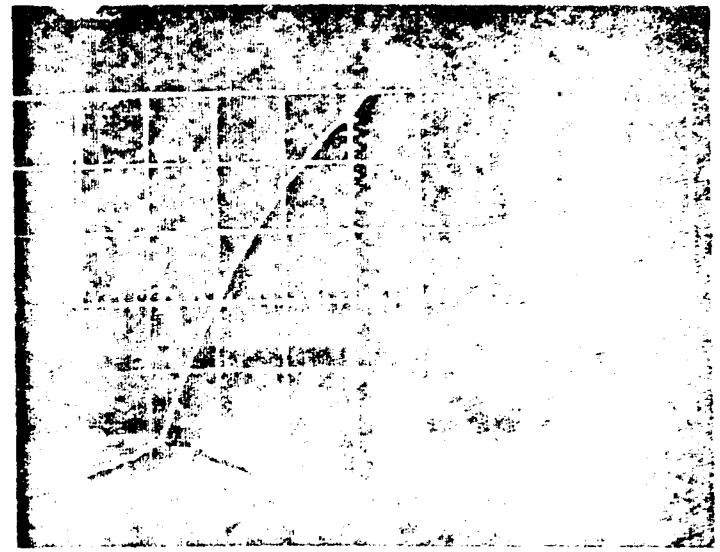


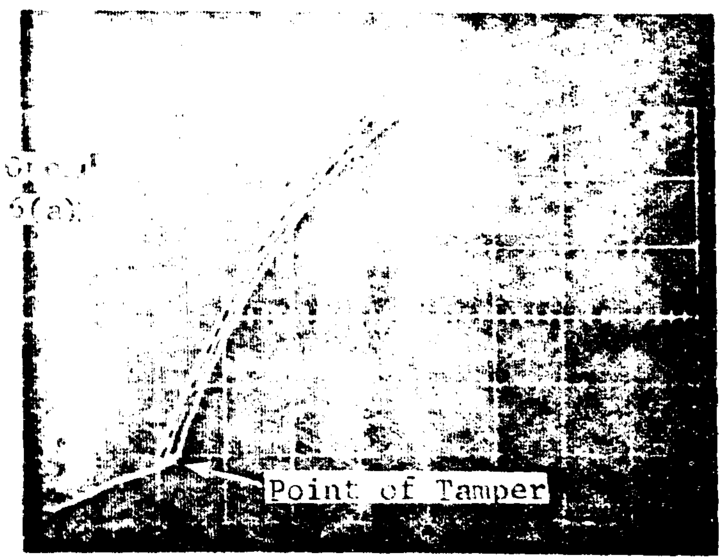
FIGURE 5. Schematic Diagram of the Preliminary RG-178 B/U Test Setup



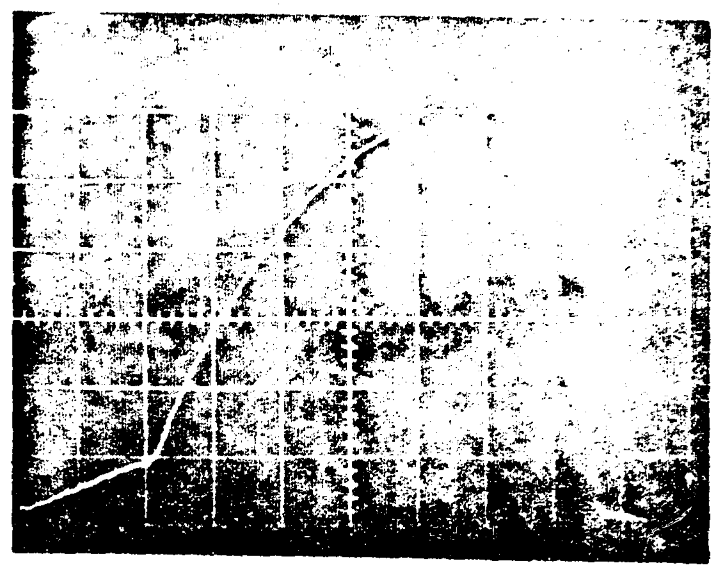
(a) Z_1 = Open



(b) Z_1 = 10 K ohm

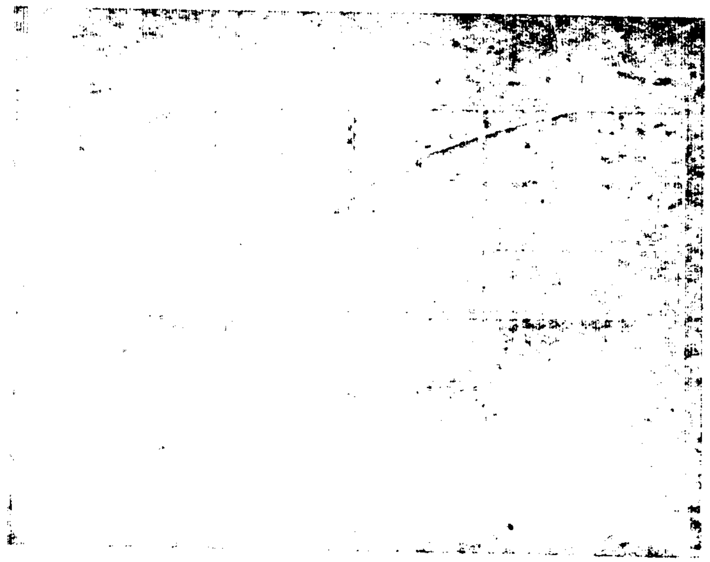


(c) Z_1 = 2 K ohm

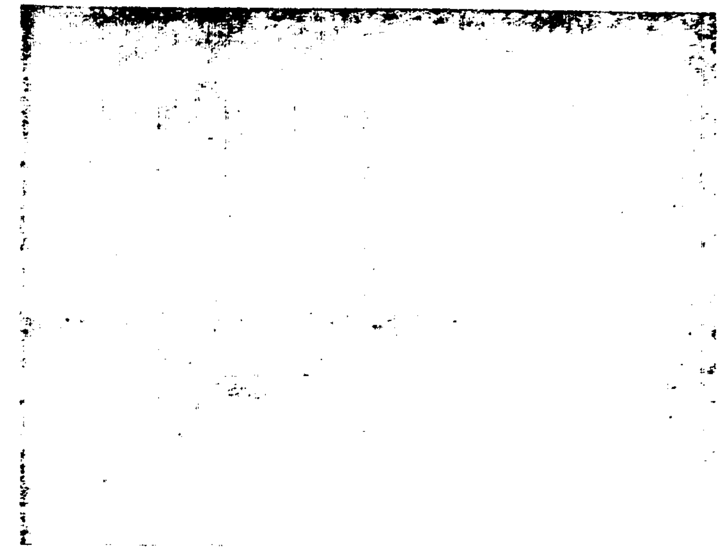


(d) Z_1 = 1 K ohm

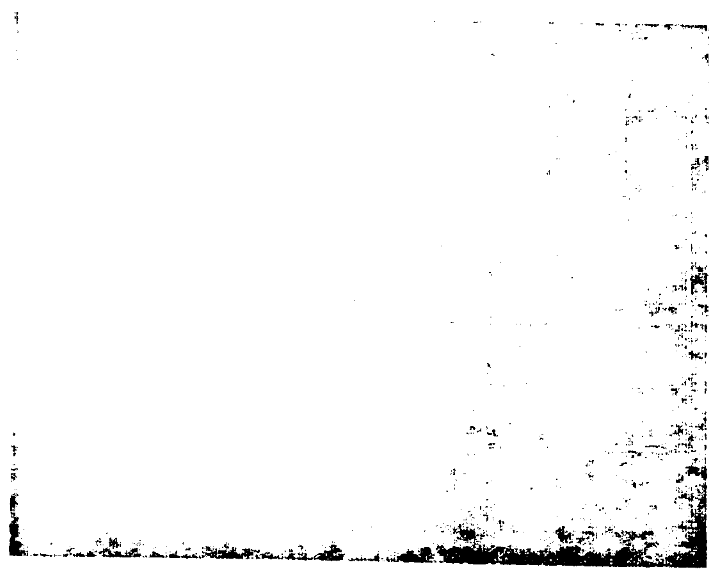
FIGURE 6. Various Impedances Attached Across End of RG-178 B/U



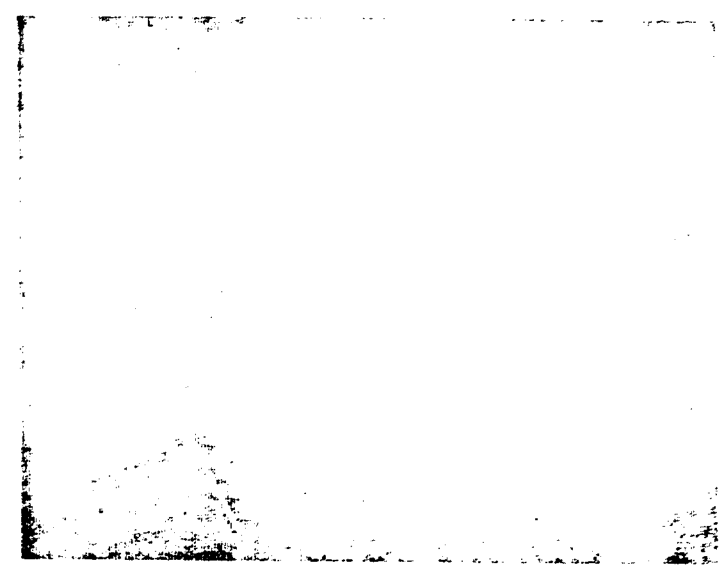
(e) Z_1 = 430 ohm



(f) Z_1 = 200 ohm



(g) Z_1 = 51 ohm



(h) Z_1 = short

FIGURE 7. Various Impedances Attached Across End of RG-178 B/U

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III. DATA LINK EVALUATION EXPERIMENTS AND RESULTS

A. GENERAL

The data link evaluation experiments were conducted at NBS with NBS personnel performing the tampering operations and BDM personnel recording the X-Y traces. The equipment setup for testing the RG-231/U cable was essentially the same as the setup for the preliminary testing (figure 3). An X-Y recorder, Hewlett-Packard Model 7000 A/Moseley Div., was used to generate X-Y traces instead of utilizing an oscilloscope and polaroid camera. Oscilloscope pictures were utilized in the preliminary test. The data was also to have been digitized and stored on magnetic tape for later computer analysis. This was not possible, however, because of difficulties with the special magnetic tape recording equipment.

The probes used during this experiment were designed and built by NBS. A more detailed discussion of the characteristics of the probes can be found in the FT-45 final report since the design developed during FT-45 was utilized during the supplemental testing program.

The equipment setup for testing the RG-178 B/U was altered slightly from the setup used during the preliminary test. A schematic of the arrangement of the equipments is contained in figure 8.

The basic change in the test setup was the location of the tamper and the addition of an X-Y recorder. The location of the tamper was shifted away from the end because in an operational system the end would be attached to the sensor and protected from tampering.

B. TEST PROCEDURES

1. RG-231/U. Nine series of experiments were performed in evaluating the RG-231/U coaxial cable. Prior

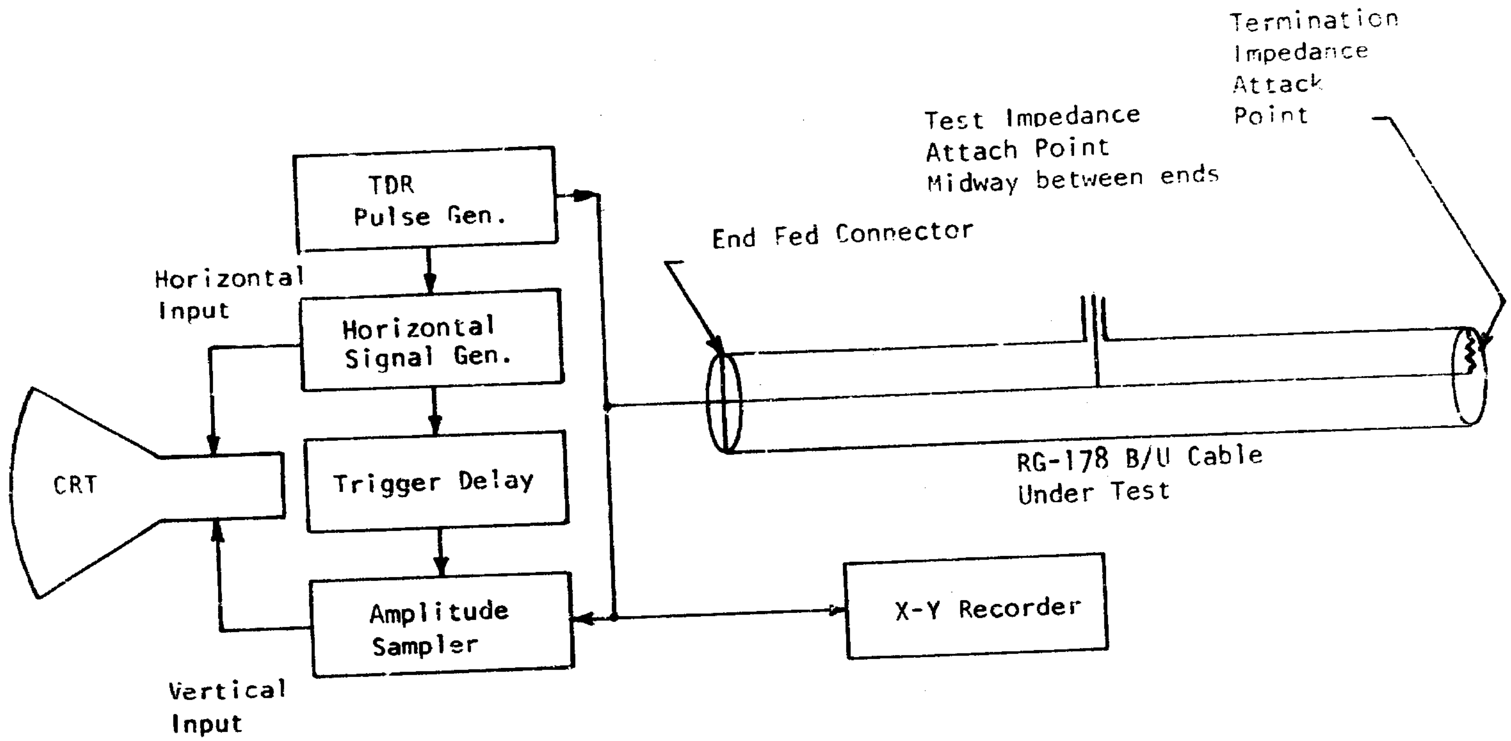

FIGURE 8. Schematic Diagram of the Final RG-178 B/U Test Setup

to tampering with the cable, two X-Y traces were made of the clean cable. After each test event, two more X-Y traces were made. Each series of tampers was performed on a clean unused section of the cable. A summary of the nine series is contained in figure 9.

After analysis by BDM of the known tamper X-Y traces, series 2 through 8, the ninth series of unknown traces were given to BDM for evaluation. The tamper conditions of this series were unknown to those interpreting the X-Y traces. The results of this evaluation, which was controlled by ACDA personnel, are contained in paragraph III.C.6.

The second and eighth series of experiments were identical in procedure and were designed to determine the minimum outer hole diameter which could be detected. The hole size ranged from 1/16-inch diameter to 9/32-inch diameter. Certain tamper conditions in this series involved the use of switching diodes. The experiment was repeated in the eighth series because of a noisy cable signature which existed during the second series.

The third series of experiments determined the threshold for detecting holes in both the outer and inner conductor. Hole sizes ranged from a 1/16-inch outer, 1/16-inch inner hole up to a 3/16-inch outer, 9/64-inch inner hole.

The fourth series investigated the ability to detect probes. A 5/32-inch outer, 3/32-inch inner hole was cut to provide access for the probe. This hole size was on the threshold of visibility on an X-Y trace. The probes ranged from 414 ohm to 623K ohms. In all cases, the probe was inserted through the cable and onto the RG-178 B/U cable.

The fifth series of experiments was designed to determine the effects of dents on the TDR signature of the cable. Dents were made with a special device having a 9/32-inch diameter hemisphere at the point of

Series	Type of Experiment
1	Since waves were put through the entire system to check the overall frequency response*
2	Holes cut in the outer conductor only
3	Holes cut in both the outer and inner conductors
4	Probes inserted through a hole in the outer and inner conductor
5	Dents
6	Ninety-degree bends
7	One-hundred-eighty degree bends
8	Repeat of series 2 - Holes in outer conductor only
9	A controlled experiment with tamper-conditions unknown to those interpreting the traces

FIGURE 9. RG-231/U Experiment Summary

*This information recorded on magnetic tape only, therefore there was no analysis.

contact with the outer RG-231/U conductor. The hemisphere had a 1/27-inch vertical deflection per turn. Dents ranging from one-half turn to three turns were made.

The sixth and seventh series investigated the effects of 90^{o} and 180^{o} bends, respectively on the TDR signature. The bends were made using a 6-inch radius mandrel.

2. RG-178 B/U. Two series of experiments were performed in evaluating the RG-178 B/U coaxial cable. The TDR unit was fed into one cable end and the opposite end was terminated in two different impedance conditions. The first series of tests was conducted with the cable terminated in an open end (infinite impedance). The second series was conducted with the end terminated in the cable's characteristic impedance of 51 ohms. Since the method of evaluating the data is dependent upon the sensitivity of the X-Y recorder, several different sensitivity settings were used while conducting the test. The sensitivity setting dictated the length of cable displayed on the X-Y plot and a high sensitivity, short cable length scan was needed to detect small changes in the slope or small discontinuities in the TDR signature.

During the test, the value of the tamper impedance ranged from 51 ohms to 20K ohms. The open and short conditions were also investigated. All tests were conducted at the midpoint of the cable, 115 feet from the end.

C. RESULTS

1. General. The results contained in this section are based on the interpretation and evaluation of X-Y traces by researchers experienced in the field of reading TDR signatues. On-line monitor techniques offer a fast, systematic, objective, and accurate way of evaluating TDR signatures but, due to technical problems with the magnetic tape recorder equipment, this technique was

not utilized during the experiment. A more detailed analysis and discussion of on-line monitor techniques is contained in the FT-45 final report.

The terms used to describe the detectability of a tamper condition are (1) definitely detectable, (2) marginally detectable and (3) not detectable. Marginally detectable is defined as being near the threshold of detection such that the tamper appears to have generated discontinuities just barely discernible in the TDR signature and such that a tamper of greater degree would definitely generate detectable changes or discontinuities in the signature.

The degree of a tamper is defined as the extent or measure of the tamper condition. For example, the larger the hole in the cable, the greater the degree of tampering.

During the entire testing program, all tampers on the RG-231/U cable were performed near the end of the cable, the worst test condition, and at no time was the tamper less than 170 feet from the TDR unit.

2. Detection of Holes and Probes in RG-231/U. In this series (number 2, figure 9) of tests, holes were cut into the outer conductor only and did not penetrate the inner conductor. These holes varied in diameter from 1/16-inch to 9/32-inch and were cut in 1/32-inch increments. It was determined that a 3/16-inch hole is definitely detectable and a 1/8-inch hole is marginally detectable.

The number 3 series of tests involved cutting a hole in both the outer and inner conductors. The same size hole was cut in both conductors during each run and varied in diameter from 1/16-inch to 9/64-inch in 1/64-inch increments. One additional run was made with the hole in the outer conductor increased to 3/16-inch. A 1/8-inch hole, outer and inner, was definitely detectable, while a 7/64-inch hole, outer and inner, was marginally detectable.

In additional runs during both of the above series of tests, diodes were inserted into the holes to determine the feasibility of fabricating a switch which could control a probe being used to insert false data onto the line. This concept of data tampering is based on the technique of monitoring the TDR pulses and having a diode switch turn the false data input on when the TDR protection system is off. The diode was both back and forward biased and in both cases it appeared as a definitely detectable short circuit on the X-Y trace. Because of the obvious tamper effects generated by this technique, it was determined to be unacceptable as a method of tampering.

The number 4 series of tests was performed to determine the threshold in terms of resistance for detecting probes which might be used to monitor or alter the data. A hole 5/32-inch diameter in the outer conductor and one 3/32-inch diameter in the inner conductor were used to insert each probe. These holes were marginally detectable on the X-Y trace but smaller holes would not accommodate the probes used in this experiment. The probes varied from 414 ohms to 623K ohms and all probes were definitely detectable.

3. Effects of Dents on RG-231/U. It was determined that the cable is very sensitive to dents. A dent of 1/27-inch vertical deflection (one turn of the device) was definitely detectable. Dents of 2/27-inch vertical deflection and greater produced large distortions in the TDR signature.

4. Effects of Bends in RG-231/U. There were two series of tests conducted to determine the effects of bends on the cable. Figure 10 shows X-Y traces made during the 90°-bend experiments. The first set of traces 601A-601B are signatures of a clean cable prior to any tampering. Traces 608A and 608B were made after the cable had been bent 90° at 1.5 meters from the end. Traces 611A and 611B were made after the cable had been bent and straightened four times and bent a fifth time

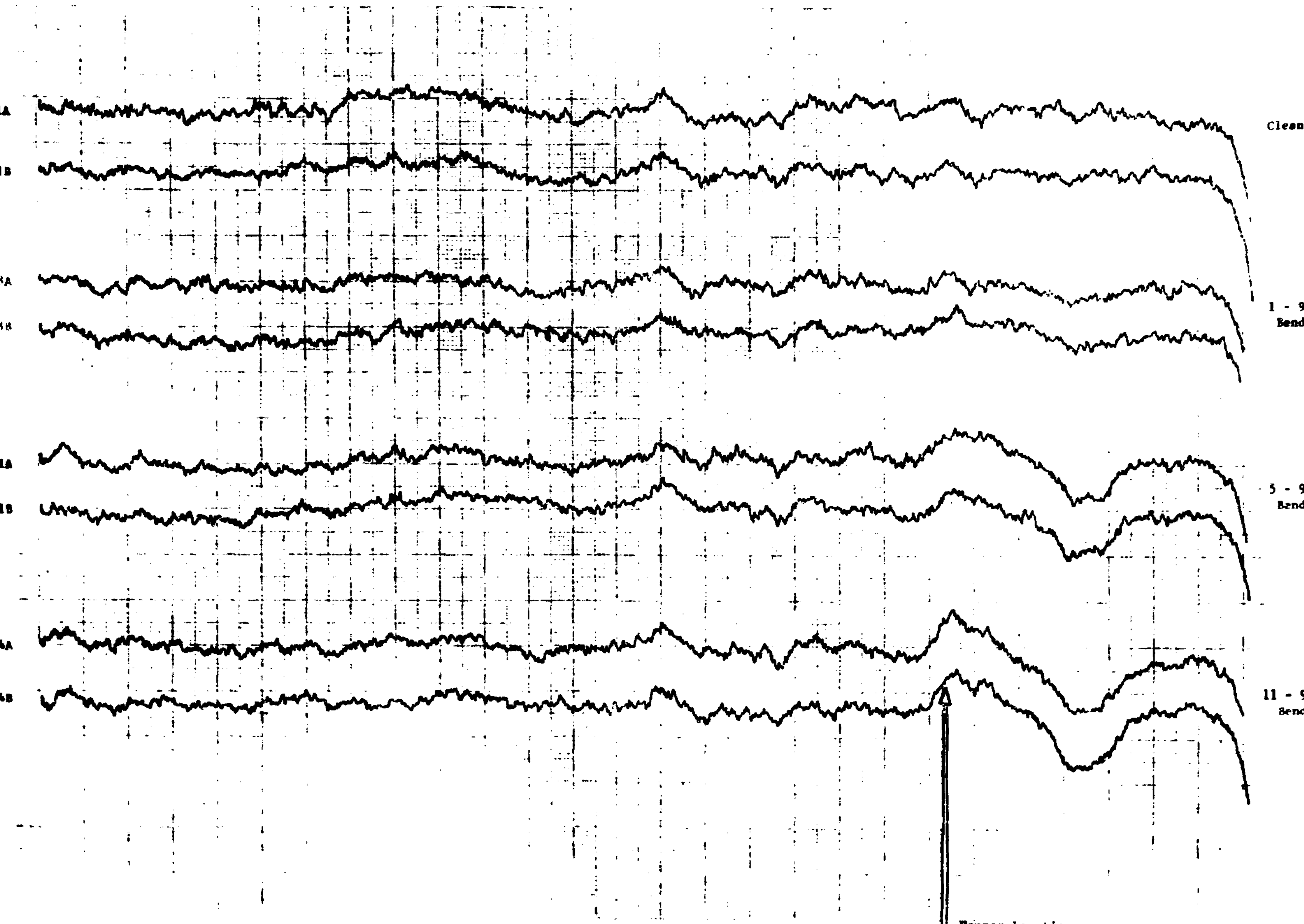

FIGURE 10. Series 6, 90° Bend Experiment

at the same point on the cable. The last set of traces was made after 11 bends. As this figure shows, one 90° bend is marginally detectable and five 90° bends are definitely detectable. The second series involved 180° bends and again it was found that one 180° bend is marginally detectable while two and one-fourth 180° bends are definitely detectable.

5. Impedance Detection in RG-178 B/U. The TDR technique used to detect tampering on the inner coaxial cable was different from the technique used on the outer cable and in previous FT-45 tests. As discussed previously in the preliminary testing section, paragraph II.B.2., an inspector is searching for a change of impedance in the cable which manifests itself as a change in the slope of the TDR signature. For example, consider figure 11 which was an actual test in which the cable was terminated in an open end and a 2K ohm resistor was attached across the cable at its mid-point (115 feet). This impedance is definitely detectable by noting the discontinuity of the signature at 115 feet in comparison with figure 12, which is the same cable without the resistor attached.

Results of the tests show that a change in the TDR signature was apparent under all test conditions. However, some of these changes were very slight and may not be sufficient for detection in any practical system. Three system parameters, (a) test cable termination (b) tamper impedance (3) monitoring system sensitivity, were varied during the tests. The results indicated that with the three parameters operating in a feasible and acceptable mode a 2K ohm impedance is definitely detectable and a 10K ohm impedance is marginally detectable.

Data alteration using a 10K ohm impedance or larger probe is unfeasible. In order for the evader to inject false data, he must dissipate an amount of power in the probe proportional to the power level of the data pulse. The proportional factor is the ratio of the impedance of the probe to the source impedance. For the

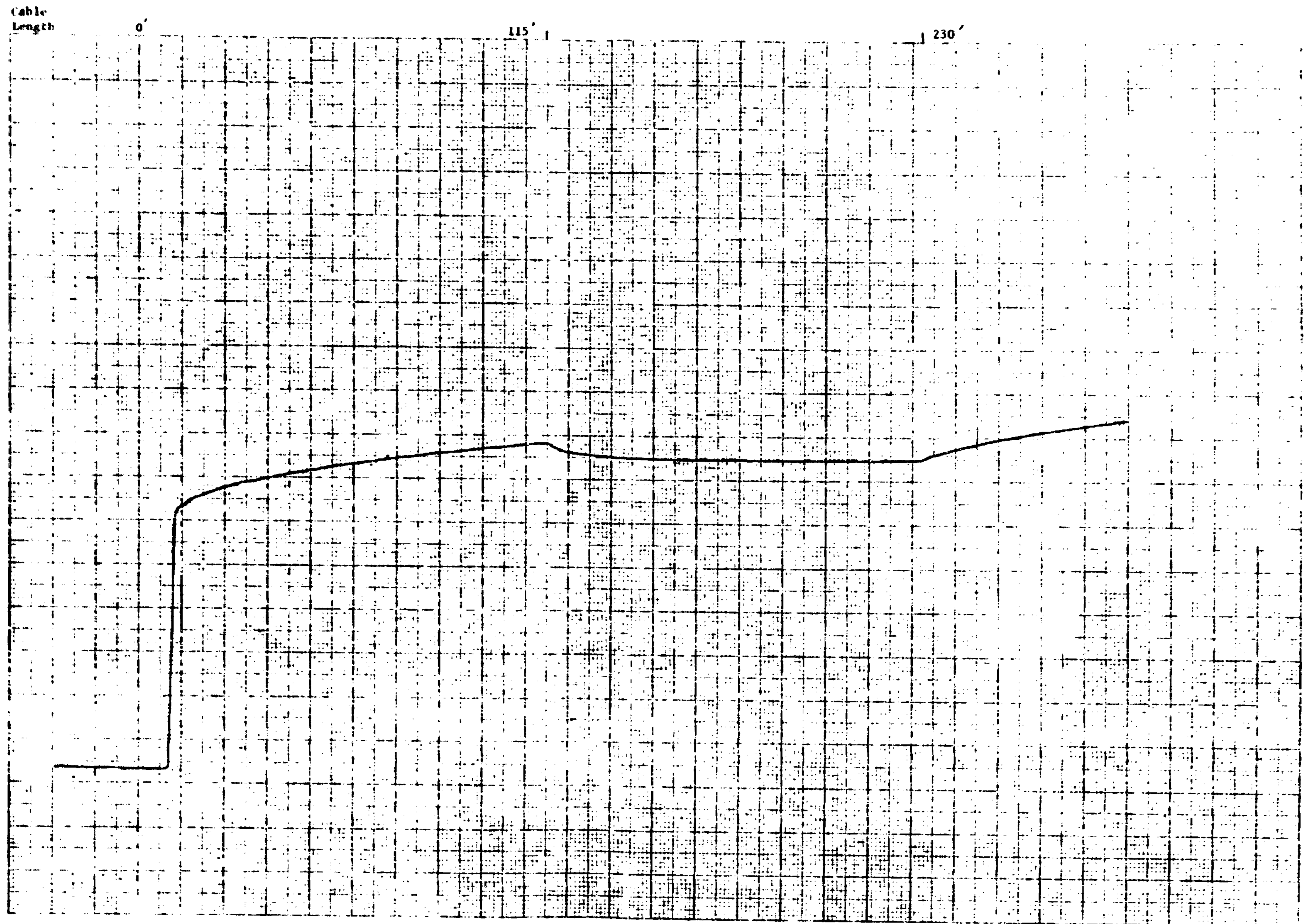

FIGURE 11. Cable TDR Signature With 100-ohm Probe Connected at 115 Feet

NOT REPRODUCIBLE

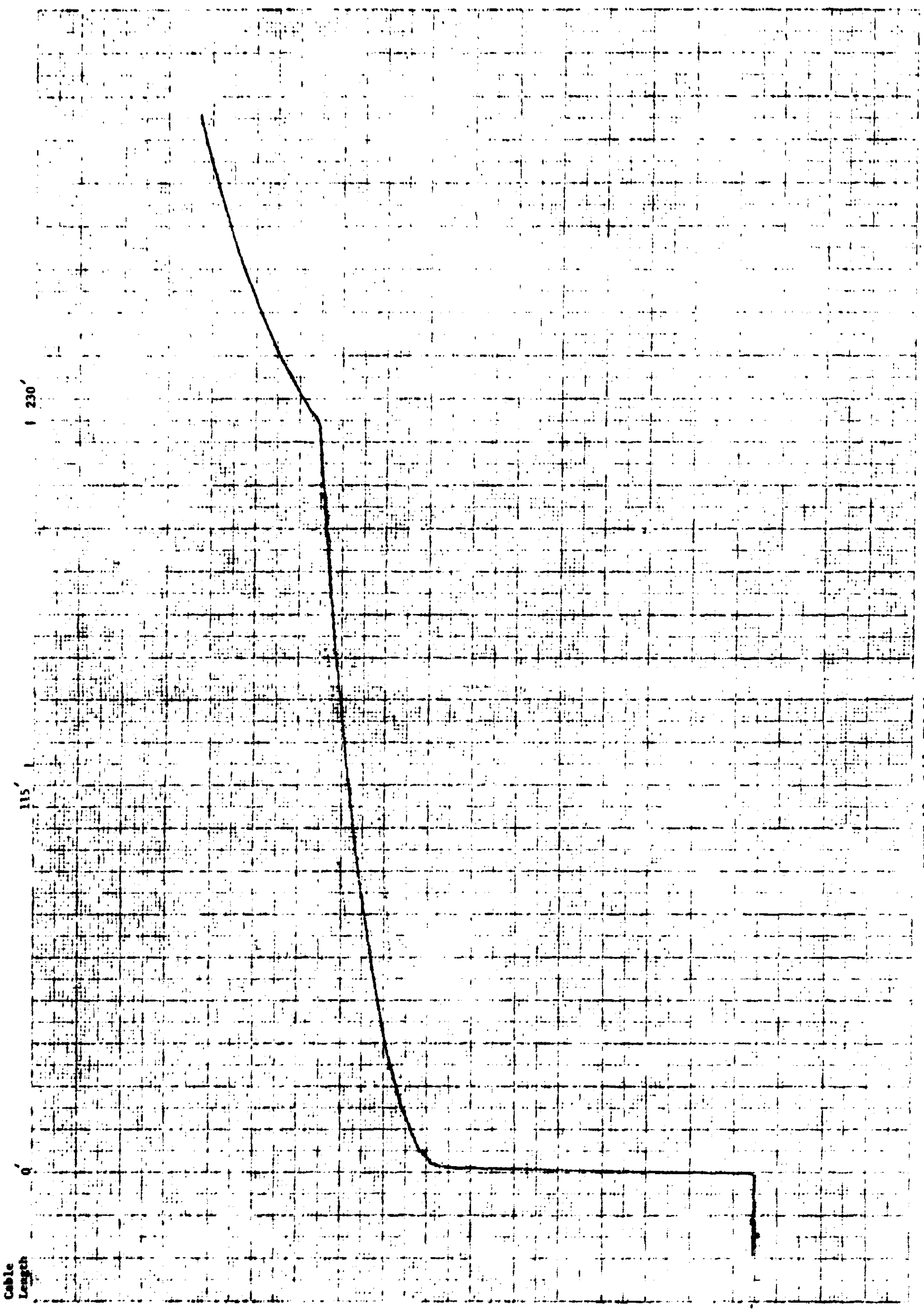

FIGURE 12. Cable TDR Signature Without Probe at 115 Feet

RG-178 this factor would be 200 (10,000/50), therefore the evader must supply 201 watts per watt of transmission data and of the 201 watts supplied, 200 watts must be dissipated in the probe. Since the input power level of the data pulse can be adjusted, it becomes impossible for the probe to dissipate the required amount of power.

Maximum monitoring system sensitivity was not achieved and the results reported above are based on a sensitivity somewhat less than maximum. However, the results establish the validity of this technique and indicate that additional work is needed to optimize the parameters and determine the limits of detection.

6. Controlled Detection Experiment on RG-231/U. Following the above experiments performed jointly by BDM and NBS, ACDA with technical assistance from NBS, using a clean test cable, performed a ninth series of tamper operations which were not known to those analyzing the traces. The TDR traces were then arranged for a controlled test. The purpose of this test was not to determine quantitatively the limits of detection but to confirm the objectivity of the analyzed experimental data.

The test was given to three different people each with a varying degree of proficiency in reading TDR signatures. The first inspector (FO) had little experience in reading X-Y traces. The second inspector (SAN) has read traces before but had not been active in the field for at least 12 months. The last inspector (BDM) had been working in this area and had a high degree of proficiency.

The test was formulated with the more difficult to detect tampers appearing first. Each inspector was given a trace of the clean cable and allowed to use a light table. Time was kept for each inspector and only one tamper trace could be inspected at a time.

The time required by the inspectors to analyze each trace ranged from 5 to 10 minutes for the more

difficult traces to 2 to 5 minutes for the more obvious tampers. The test results are contained in figure 13. Figure 14 compiles the data into table form and shows the percentage of detection. It should be noted that only one false alarm was recorded during the test. The number of times that detection was achieved by the 50-cm correlation techniques confirms the importance of this technique in inspection and verification technology.

In general the series 9 test results agreed with and validate the analysis of the series 2 through 8 test data. This series also emphasized the unacceptable amount of time an inspector needs to analyze traces and to point out the importance of on-line monitor techniques.

Test Condition \ Inspector	Trace	FO	SAN	BDM
Clean Cable	A	1	1	1
	B	1	1	1
3/32"-Outer Hole @ 1.3m	A	0	1,F	1
	B	0	1	0
3/32"-0 Hole @ 1.3m; 5/32"-0, 3/32"-I Hole @ 2.35m	A	0,1	0,1	0,1
	B	0,0	1,1	1,1
3/32"-0 Hole @ 1.3m; 1/8"-0, 3/32"-I Hole @ 2.35m		0,0	0,1	0,1
9/32"-0 Hole @ 1.3m; 5/32"-0, 3/32"-I Hole @ 2.35m	A	1,1	0,1	0,1+
	B	1,1	0,0	1+,1+
3/32"-0 @ 1.3m; 1/8"-0, 3/32"-I @ 2.35m with Probe at 2.35m having resistances of:	4KΩ	0,1	0,1	1,1
	19.5KΩ	0,1	0,1	1,1
	95KΩ	0,1	0,1	0,1
9/32"-0 Hole @ 1.3m Dent Tuned; 5/32"-0, 3/32"-I Hole @ 2.35m	A	0,1	0,0	0,1
	B	0,0	0,1	1+,1
9/32"-0 Hole @ 1.3m Dent Tuned; 5/32"-0, 3/32"-I Hole @ 2.35m; 7/64"-I/0 @ 3.63m	A	0,1,0	0,1+,0	1+,1+,0
	B	0,1,0	0,1+,0	1+,1+,0

+ Detection Achieved by 50 cm Correlation Technique
A The first of a set of 2 traces of the same test condition
B The second trace

Score:

0 - Represents the failure to detect a penetration which was present
1 - Detection of a penetration or test condition which was present or indicative of no tampering
F - Represents a false alarm which is defined as a false detection

FIGURE 13. Controlled Detection Results

	FO Traces	FO Det.	%	SAN Traces	SAN Det.	%	BDM Traces	BDM Det.	%
3/32" Outer Hole	7	0	0	7	3	43	7	4	55
9/32" Outer Hole	2	2	100	2	0	0	2	1	50
9/32" Outer Hole Dent Tuned	2	0	0	2	0	0	2	1	50
7/64" O/I Hole	2	0	0	2	0	0	2	0	0
1/8"-0 3/32" I Hole	1	0	0	1	1	100	1	1	100
5/32"-0 3/32" I Hole	8	6	75	8	6	75	8	8	100
Probes	3	3	100	3	3	100	3	3	100

FIGURE 14. Detection Probability in Percent